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# Beneficial Reuse of Dredged Marine Soils (DMS) with the Inclusion of Cement and Granular Material for Engineering Applications

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**Abstract:** Plenty of geowaste in Malaysia namely dredged marine soils (DMS) has been increasing over the year. The management of DMS after dredging has become a worldwide problem. Conventionally, the materials are disposed back to the sea. As the minimization of the dredged material during dredging is impossible, extensive work has been done by researchers to develop various economical and viable solutions, such as beneficial reuse of DMS. Series of one-dimensional test by using oedometer were tested on DMS with the inclusion cement and mining sand. Based from the results, the cement- and sand-treated DMS have resulted with low settlement reduction, thus increase its effective yield stress and improve its compressibility. As conclusion, it is suggested that DMS can be beneficially reuse for engineering application such as land reclamation or backfills.

**Keywords:** Dredged marine soil, cement, granular material, beneficial reuse.

## 1. INTRODUCTION

### 1.1. Soil Improvement of Dredged Marine Soils (DMS)

Generally, the properties of dredged marine soils (DMS) are similar to natural soft clays as displayed in Figure **1**. DMS are type of soil with low shear strength ($c_u$<50 kPa), high natural water content which exceed its liquid limit and may be contaminated with heavy metals and organic compounds [1]. Soil improvement method modifies the soil characteristics by inducing stronger material in soil. Chemical binder and granular material are commonly used in soil improvement. Chemical binder such as cement can be used to solidify and stabilize DMS, thus enhance its engineering properties, namely strength, compressibility and permeability. It is a process of using chemically-reactive formulation together with water to form a stable solid. Other than to improve the soil's engineering properties, these materials also insolubilize, immobilize, encapsulate, destroy, sorb or interact with selected components. Alternatively, this method is known as soil stabilization. It produces a solid form which is non- or less hazardous than the original soil. The effectiveness of solidification or stabilization products are often gauged through their strength and leach resistance [2]. In addition, it could improve and stabilize the soil's chemical characteristics to minimize the rate of contaminants migration.

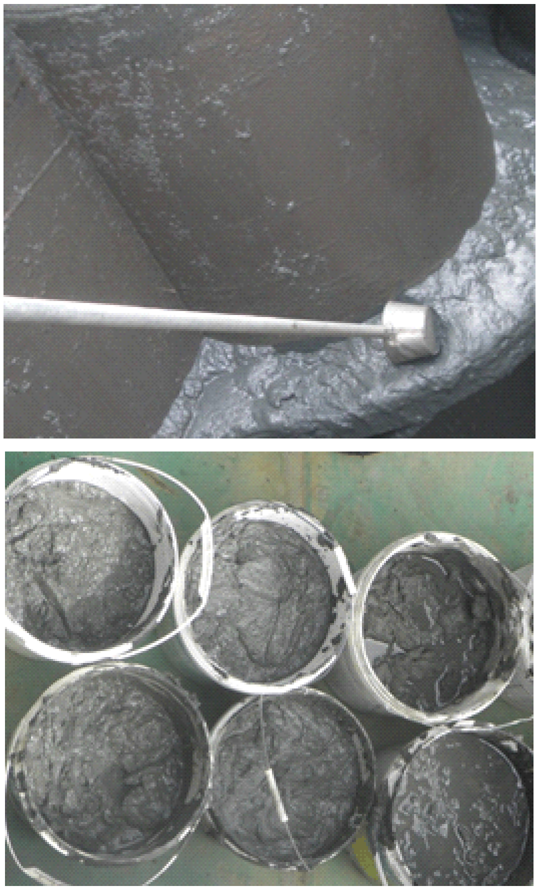

**Figure 1:** DMS (Kuala Muda, Kedah) were scooped out from sedimentation chamber (*left*) and transferred into storage bins (*right*).

As mentioned, solidification is a method that improves the soil's properties such as strength. Solidification can be divided into two categories, namely mechanical and chemical solidifications. Mechanical solidification improves the soil's strength by

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mixing it with aggregate or granular material, whereas chemical solidification enhances the soil's strength by mixing the soil with chemical binder. Sand is a common material used in construction industry especially for land reclamation works [3]. It can be layered on top or in between of DMS layers to accelerate consolidation settlement, which has been used in many land reclamation projects such as Kansai International Airport, Changi Airport and Manila Bay [4-7]. Sand as filler material helps to stiffen DMS by providing the soil with structure [8 and 9], have reported that the mixture of clay and sand had resulted with rapid consolidation and high permeability. Therefore, solidified DMS can be reused as fill materials for land reclamation including the creation of artificial islands, restoration and rehabilitation of eroded shorelines [1, 10, 11]. Moreover, the solidified DMS are capable to resolve the present issue in minimizing the impact of DMS to the environment

### 1.2. Soil Improvement for Contaminated Dredged Marine Soils (DMS)

Contaminated soil poses threat to human, animal and environmental health. It is also indirectly causing financial implications such as removal costs and restoration problems [12, 13]. Numerous studies have shown the efficacy of cement as an immobilizing agents. Cement is the most adaptable binder for the immobilization of the toxic heavy metals. It is also considered to be an effective and practical approach to remediate contaminated soils. This is because the toxic heavy metals will not undergo chemical or microbial degradation. It will persist for longer duration in site and the concentration usually do not change after their release [12]. Solidifying or stabilizing contaminated soils with high level of heavy metals display an economical and practical remediation technology. The solidifying or stabilizing agent such as cement will reduce the contaminant's leachability, thus improving its mechanical properties [14]. The cement-based solidification or stabilizing sample could lower the leaching rate and bioavailability. It could reduce the transfer of metal pollutants or residues to food web. It is an attractive option in handling the polluted soil to facilitate land use and reduce the release of contaminants into the environment. Furthermore, the immobilization or solidification of soil are cost effective and less disruptive towards the environment [12,15,16].

Solidification or stabilization of soil will primarily alter its physical properties. Hence, it will no longer contain free liquids and improve its strength. The treated soils are much easier to handle and able to reduce the permeability and the advective flow through the soil. If the permeability value of treated soil is much lower than the surrounding materials, the fluids will flow around the treated soil rather than to pass through it. Therefore, it will minimize the release of contaminants [17]. The major factor that affect solidification is the mix design of binder and soil. It will influence on its strength, hydration, carbonation, pore structure, pore volume and environmental factors [18]. Binder will bind together pozzolanic material to reduce the rate of hydration kinetics as well as the effect of carbonation. The carbonated solidification product will develop a higher strength material [17, 18].

As explained, the strength of cement-treated DMS depends on sample mix design, curing period and temperature. Whereby, the longer curing period and higher curing temperature lead to the optimum strength in cement-treated DMS [19]. The improvement of its engineering properties were contributed by several reactions. There were pozzolanic reaction, cation exchange reaction, flocculation and agglomeration [1, 20]. A study by [20] presents the properties of cement-solidified DMS from Dunkirk, France. Based on the study, the optimal water content of solidified DMS decreases with the increase in cement content, the strength increase generally with cement content and curing time and the addition of cement could restrain the swell potential of raw DMS.

### 1.3. Beneficial Reuse of Dredged Marine Soils (DMS)

As the minimization of the DMS volume during dredging is feasible, extensive work has been done by researchers to develop various economical and possible reuse of DMS. It is a process where DMS is being reutilize as raw material in obtaining productive materials for construction brick, pavement base material and many more [21, 22]. The suitability of DMS as a fine aggregate in ready-mixed concrete has been investigated by [23]. The authors studied the use of untreated and treated DMS in ready-mix concrete as a fine aggregate. Treated DMS were subjected to washed (desalination), dewatering by filter-press and drying at 105 °C while untreated DMS were dried only. The study had demonstrated that treated DMS can be used as fine aggregate with no mechanical, physical and environmental impacts. However, contaminated DMS require pre-treatment process to lessen the content of chloride and sulphate.

**Table 1: Beneficial Reuse of DMS**

| Authors | Materials & Methods | Beneficial Reuse |
|---|---|---|
| [31] | Dredged marine soils | Landfill liner material to remove pathogenic bacteria in landfill leachate |
| [28] | Solidification of dredged marine soil with low dosage of cement | Reusing the solidified DMS as geomaterial or fill for reclamation works |
| [29] | Admixture DMS with sand, palm oil clinker and recycled pavement materials by using 1D consolidation tests. | To hasten the consolidation time rate |
| [26] | Phytoremediated of DMS using *Paspalum vaginatum* (seashore Paspalum) | Peat-free growth substrate for ornamental plants |
| [27] | Co-composting of DMS with urban green waste | Technosols for nursery or degraded land vegetation |
| [23] | Desalination of DMS followed by dewatering by press filter and dried at 105 °C | Fine aggregate in ready-mix cement |
| [24] | Solidification/stabilization of dredged marine soils with coal fly ash and lime as partial replacement of cement | Fill material in construction |
| [30] | Dredged material and construction and demolition (C&D) waste. | Landfill liner |
| [22] | Dredged material mixed with sand and cement | Alternative material for road construction |

A study by [24] had proposed a mixture designs and treatment method for contaminated DMS. The study aimed to recycle the contaminated DMS so that it could be reused as beneficial resources for various application. The researchers assessed the function and integration of binder formulation, DMS pretreatment, curing method as well as waste inclusion in stabilization or solidification. The results suggested that the usage of coal fly ash and lime as partial replacements of cement in solidification of stabilization of DMS with binder-to-DMS ratio of 3:7 could be used as fill materials for construction industry. A study by [22] have investigated the potential reuse of DMS as an alternative material for road construction. The DMS were mixed with several type of material such as sand, 6% of cement and CEM2 (cement contains 67% of slag and 12% of limestone). The study has identified that the mixture of DMS with sand as well as 6% of cement were suited to be used for foundation and base layers in road construction. Meanwhile, mixture of DMS with CEM2 was only suitable for foundation layer.

A potential of DMS to be reuse as landfill liner material for removing pathogenic bacteria in landfill liner have been appraised by [25]. Outcomes from the study showed that the DMS's hydraulic conductivity were within the range as stated in the International Solid Waste Association (ISWA) guidelines for selection of liner material. Other than that, the bacteria isolated from landfill leachate was found to be able to survive at such extreme saline environment. This finding has endorsed the hypothesis that the use of DMS was able to adsorb bacteria in landfill leachate. In addition, the use of DMS will help to protect ground water sources from being contaminated by bacteria originated from landfill activities. Table **1** summarize the study by previous researchers on the beneficial reuse of DMS.

## 2. MATERIALS AND METHODS

### 2.1. Materials and Properties

The materials used in this study are DMS, cement and mining sand. The soil samples were retrieved from Kuala Muda, Kedah and Kuala Perlis, Perlis. In Kuala Muda, the disturbed soil sample was dredged at depth of 8-10 m from sea level by using a trailing suction hopper dredger which is located about 1.5-2 km from the terminal jetty. As for soil sample in Kuala Perlis, the soil was dredged at depth of 4-6 m from sea level by using a backhoe dredger which located 300 m from the jetty. Figure **2** displayed the relative dredger used for soil sampling. Based on the personal communication with Malaysia Marine Department personnel, the annual volume of dredged materials is as listed in Table **2**. All of the soil samples were manually scooped into air-tighten storage bins. On land, the bins were kept indoor to prevent any moisture loss from heat and sunlight. Cement powder was used as hydraulic binder and mining sand was used as granular material which represents the chemical and mechanical solidifications respectively.

**Figure 2:** Trailing suction hopper dredger (*left*) and backhoe dredger (*right*).

**Table 2: Annual Volume of DMS in Some Part of Malaysia**

| State/District | Annual volume of DMS ($m^3$/year) |
|---|---|
| Perak | 120,000 |
| Melaka | 120,000 |
| Kelantan | 140,000 |

**Table 3: Physical Properties of DMS**

| Properties | Kuala Muda, Kedah | Kuala Perlis, Perlis |
|---|---|---|
| Initial water content, $w_c$ | 91.96 % | 218.07 % |
| Specific gravity, $G_s$ | 2.57 | 2.68 |
| Liquid limit, LL | 47.70 % | 66.50 % |
| Plastic limit, PL | 31.50 % | 55.80 % |
| Plasticity index, PI | 16.20 % | 10.69 |
| pH | 8.0 | 8.0 |
| $w_c$/LL | 1.93LL | 3.27LL |
| Soil classification (USCS) | ML | MH |

The physical properties of DMS in Kuala Muda, Kedah (KM) and Kuala Perlis, Perlis (KP) are tabulated in Table **3**. The index value of water content and liquid limit ($w_c$/LL) for DMS in KP is thrice its liquid limit and much higher than DMS in KM which twice its liquid limit. It shows that the soil in KP is too soft and slurry as compared to DMS in KM. Figure **3** indicates the particle size distribution of DMS and mining sand. According to Unified Soil Classification System (USCS), DMS in KM and KP were classified as low plasticity silt (ML) and high plasticity silt (MH) respectively, whereas mining sand was categorized as medium-sized sand.

## 2.2. Sample Preparation

In this study, DMS were admixed together with cement and mining sand. The percentages of cement and mining sand were determined by dry weight of soil. The amount of sample's mixing water was remained at its natural water content. Note that 50 % of mining sand was used for both DMS, KM and KP to observe the effect of granular material inclusion in DMS. Only DMS KM was admixed with 10 % of cement to differentiate the effect of cement- and granular-admixed DMS. Table **4** summarized the proportional mix of cement and mining sand. All of the pre-measured materials were then mixed by using conventional kitchen mixer for 5-10 minutes. The mixer was initially run at low

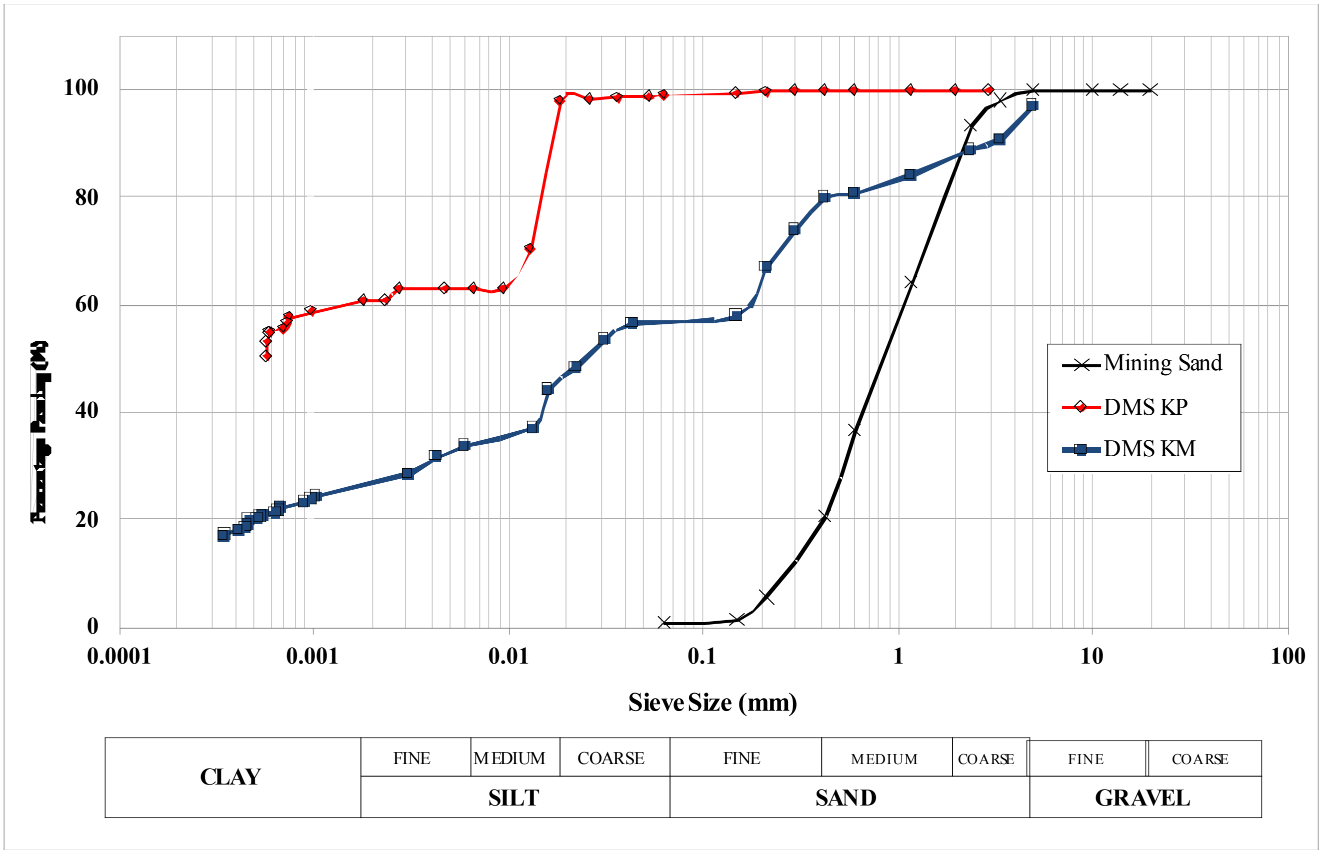

**Figure 3:** Particle size distribution of DMS and mining sand.

**Table 4: Mix Proportion Design**

| Samples | | Cement (%) | Mining Sand (%) |
|---|---|---|---|
| KM | Untreated KM | - | - |
| | 50S KM | - | 50 |
| | 10C KM | 10 | - |
| KP | Untreated KP | - | - |
| | 50S KP | - | 50 |

speed to avoid spilling the sample, followed by a higher speed for 1 minute. Then a plastic spatula was used to gather the mixture into a lump for uniform distribution, then transferred and compacted into standard oedometer ring. Note that only cemented-DMS sample was left to cure for 7 days prior to testing. The samples were tested for settlement by using oedometer test which the test procedures were accordance to British Standard.

## 3. RESULTS AND DISCUSSIONS

The compression curves of soil samples admixed with mining sand and cement were displayed in Figure **4**. Based from the graph, it is obvious that with the addition of cement and mining sand in DMS, the settlements have reduced as compared to the untreated DMS. For comparison, the DMS in Kuala Perlis (KP) shows high settlement than DMS in Kuala Muda (KM). This is due to that higher-water content of DMS KP is susceptible to higher settlement. As tabulated in Table **5**, DMS KM has higher effective yield stress ($\sigma'_y$) than DMS KP, thus proven that high-water content DMS was physically soft and weak to sustain high vertical stress. However, in term of compressibility, both of the natural DMS are almost similar.

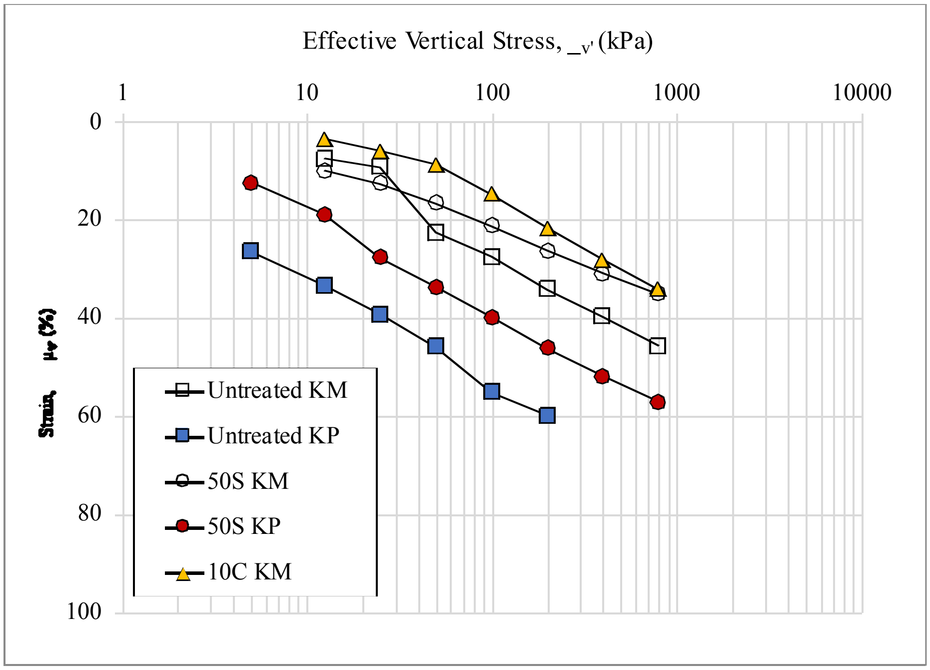

**Figure 4:** Compiled compression curves.

**Table 5: Effective Yield Stress (σ'$_y$) and Compression Index (c$_c$)**

| Samples | | σ'$_y$ (kPa) | (c$_c$) |
|---|---|---|---|
| KM | Untreated KM | 28 | 0.30 |
| | 50S KM | 42 | 0.054 |
| | 10C KM | 68 | 0.090 |
| KP | Untreated KP | 19 | 0.31 |
| | 50S KP | 25 | 0.41 |

As mentioned, the inclusion of 50 % mining sand in DMS have resulted with low settlement than natural and untreated DMS. This result may be explained by the fact that large amount of granular material in DMS has affected the shear resistance which was induced by the fricitional resistance between these materials. The findings of the current study are consistent with those of [32] who found that granular materials contribute to the formation of stiff soil skeleton which reduced the settlement and compressibility. Surprisingly, sample 50S KP has lower settlement reduction than sample 50S KM. A possible explanation for this might be that DMS KP possess high amount of water which lubricate and loosen the interparticle bond to the contact surfaces of DMS and mining sand. Furthermore, it is apparent from the σ'$_y$ and c$_c$ results of sample 50S KP are highly comparable to sample 50S KM that may be influenced by the presence of high water content.

While mining sand is an inert material that solely rely on its physical nature, cement-treated soil depends on the hydration process and pozzolanic reaction. In Figure **4**, sample 10C of DMS KM shows high settlement reduction than untreated KM and 50S KM samples. Based on the σ'$_y$ results between samples 50S KM and 10C KM, cemented DMS have proven to sustained higher effective vertical stress before the breakage of the inter-particle bonds [33]. One unanticipated finding was that sample 50S KM was less compressible compared to sample 10C KM as summarized in Table **4**. Similar result by [34] reported that sample with higher granular material could provide significant stiffness improvement which outweighs the cementation effect of cement addition. Furthermore, the result may also be due to the slow reaction of cement hydration for the rather low 10 % cement addition to the sample. Numerous researchers found that soft clay with high water content was comprised of so many cluster of clay that which surrounded by clay's inter-void spaces [35, 36]. According to [37], the inclusion of cement in clay helps to bind the clay particles at the inter-void spaces. Low amount of cement is able to collect the clay clusters in small inter-void spaces but insufficient to gather the clay clusters at large inter-void spaces. Hence, the soil developed slight increase in strength. On the other hand, if the cement content is over a threshold, the cementitious products will bind all of the clay clusters and gradually strengthen the soil. Hence, it can be suggested that by adding more cement and/or prolong the curing period for sample 10C KM, the settlement could be reduced and improved its compressibility.

## CONCLUSIONS

The purpose of this study is to beneficially reuse DMS for engineering application such as land reclamation or backfills. Based on the results, it clearly shows that the solidified DMS have reduced the settlement than the natural DMS. The summarized findings are as follows;

1. Sand-admixed DMS resulted with low settlement reduction than the untreated DMS. This is due to the frictional resistance of both materials.
2. The addition of 10 % cement in DMS KM has reduced the settlement but not that significant as compared to sample 50S KM. It is plausible that the low cement dosage in highly saturated DMS which was cured at 7 days have not yet develop any considerable effect.
3. Regardless of the materials, DMS can be reuse once again for beneficial purposes such as land reclamation or backfills.

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